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Discussion of
"RECENT TRENDS IN HYDRAULIC GATE DESIGN"

by D. A. Buzzell
(Proc. Sep. 517)

A. STREIFF,[1] M. ASCE.—There is probably no field of design which has attracted the inventive engineer more than the hydraulic gate. They are as old as civilization itself; Herodotus (450 BC) already wrote: "The great King of Persia blocked up all the passages between the hills with dykes and flood gates." In modern times one finds hydraulic gates of every conceivable system, shape and size. Vibration and cavitation are the nemesis of hydraulic gate design and are not necessarily confined to high heads. They were already encountered in 1890 at the then comparatively new Stoney gates of the Chevres powerplant on the Rhone river below Geneva.

The account given by Sir Wm. Willcocks who, at the turn of the century, tried to find an acceptable design for the deep sluice gates at the Assuan dam, is interesting. Afflicted, as we are today, by a "consulting board" of three engineers, an Englishman, a Frenchman and an Italian expert, he chose the Stoney gate, now discarded in its original form. The French expert on the committee was M. Boulé, well known here because many Boulé gates are in this country, some built by the Corps of Engineers. The C.E. has a prideful, long record of accomplishment in surface gates for canalization of rivers, contributed by such notable engineers as Brunot, Lang, Carro, Dubois, Parker, Girard, Chittenden, Marshall and many others, whose works are found in the rivers and harbors of the United States. The more recent Bureau of Reclamation launched upon a program of high head structures and collected invaluable experience in the design of high pressure outlets. Their adverse experiences are carefully set forth in the work of J. L. Savage on high pressure outlets, a most invaluable guide for designers for many years past, published by the Bureau in the twenties. The lessons contained therein have sometimes been overlooked with dismal results, as happened to the outlets of the Madden dam in the Canal Zone, the Denison dam and in other structures, such as the Keystone dam.

The author states that the C.E. has undertaken a nationwide survey of existing gate systems, extending over two years and doubtless by numerous observers. The first and obvious comment therefore on the author's very instructive paper is that engineers would welcome a publication of that report, as was done by the B.R. General taxation pays for the accepted practice of the Government to offer an unending stream of valuable guides and information for all fields of endeavor, from tables of Bessel's functions to the drilling of wells and the repair of furniture. This hydraulic gate survey would be another valuable number of the Government Printing Office, as private engineers could not engage in a two-year survey by numerous personnel, yet also contributed to the cost of this survey.

The author's belief "as late as 1946" that no greater depth than 25 feet could safely be discharged over an ogee spillway is not generally shared.

1. Cons. Engr., New York, N.Y.

The B.R. had 50 by 50 feet gates long before that time and the gates at Laufenburg on the Rhine, 56'9" by 52'6", although on a low ogee, exist since 1914. The writer designed one spillway containing 50' by 30' Taintor gates which already have passed a 500,000 c.f.s. flood with an overflow depth of 41.5 feet, and another, built in 1945, containing four Taintor gates 78'9" by 36'. Both of these stand on gravity ogee sections over 80 feet high; the first across the Colorado river in Texas and the second in the Duero river in Spain. These are the largest Taintor gates in existence to date.

The main conclusion derived from the author's paper is the reversal of the results based on the B.R. manual on high pressure outlets. This manual concluded that best results will be obtained with the gate placed at the downstream outlet of the conduit. This principle was also used by the C.E. in many installations, as at the Mud Mountain dam. Larger and larger conduits compelled what amounts to a step backwards in fact and effect; the gate moved back into the conduit. The Bureau too reversed itself; slide gates had always been retained under moderate heads with good ventilation, and the B.R. has a standard set of these in use for many years. But in recent years Paradox gates and Tube valves have been placed "inside" the spilling tubes, as at the Marshall Ford and Grand Coulee dams. The results have not been altogether happy, as it is practically impossible to design a perfect hydraulic gate under those conditions of inaccessibility, confinement and incipient cavitation. Under water corrosion, mud, calcareous deposits, barnacles, etc., soon covers everything; roller tracks deteriorate with the gates. The decision to apply Taintor gates in those locations is a bold step on a hitherto unprecedented scale which deserves applause. A cautious attitude should be reserved until years of operation have confirmed the expectations. The part open Garrison gate deprived of its fixed support may well be subject to heavy vibration as stated in the press. At 25,000 c.f.s. discharge under 169 feet head the gate would shoot a rectangular jet of $\pm$ 15 by 18 feet at some 90 feet per second into a 22 ft. diameter round conduit flowing at 66 feet per second if full, and of considerable length. This will represent an enormous hydraulic compressor of no less than 480,000 horsepower in a 22 ft concrete conduit under highly turbulent conditions. The writer fears that such use for any length of time would soon disclose similar adverse results as at the spill tunnels of the Hoover dam. It would seem more secure to disperse into smaller units. Better yet, to avoid such abnormal flood routing requirements. The value of the deep intake is debatable anyway for many reasons not connected with the gate design. Such deep intakes are in many foreign installations up to 300 feet head but only for turbine intakes and are then provided with filler gates, as at the Hohenwarte dam. Inside free discharge gates in such places are avoided.

The McNary intake gates for large Kaplan units are a big improvement over the TVA system. In Germany hydraulic operation of headgates for large Kaplan units is universal. Oil pressure is usually 800 lbs/sq. in., for starting under high head a second pump for 1680 lbs/sq. in. is temporarily added. The closing time varies from 10 to 30 seconds. At the TVA it is half an hour or more. The McNary intake seems therefore better equipped and is a big step forward. For smaller units of some 4000 c.f.s. the writer uses just one Taintor gate, 45 by 29 ft. per unit.

The Taintor gate has a long history, briefly mentioned in "Civil Engineering" of March, 1950. Inclined struts were used exclusively in hundreds of gates by Wm. G. Fargo, MASCE, retired, since 1905. The new C.E. designs are apparently still considerably heavier than existing designs, as they cost

a great deal more. The moving part of a 40 by 25 ft. gate at the Buchanan dam weighs 50,000 lbs., of the 50 by 30 ft. gates at the Granite Shoals dam 110,000 lbs. The cost of the latter, including anchorages, was in 1951 $21,650. Two traveling hoists were used for 9 gates, the cost per gate was $3910; the total cost of the gate per square foot including anchorages and hoist only $17 per square foot. The use of long steel bars to anchor the gate by bond into the pier has been usual practice for half a century. The thrust of 1,753,000 lbs. of each strut of the 78'9" by 36' gates is held by 23 imbedded and upset, prestressed 3" bars, held only by bond. Half a century of experience in the design of this type of gate has brought forth a surface gate lighter and more economical than any other type of hydraulic gate for surface spillways, and requiring a minimum of maintenance.

It is not known whether the Ft. Randall roller train sluice gates are to be operated at part gate; but if they are, their ultimate failure will only be a matter of time, in the light of all previous experience covering the period from the introduction of roller trains some sixty years ago or more. It would be of interest to know what innovations were introduced to warrant a new trial.

Discussion of
"ENGINEERING ADVANCEMENTS AT McNARY PROJECT"

by Louis E. Rydell and Glenn H. Von Gunten
(Proc. Sep. 627)

J. FISCH.[1] —The authors have given an excellent description of the overall engineering and economic features of the giant McNary Project. With reference to the hydraulic turbines it is believed appropriate to offer the following comments.

The variations in head and flow encountered at this plant, are of the same order as those at Bonneville and make the selection of the Kaplan type turbine by the Corps of Engineers here, as at Bonneville, a logical choice. The basic feature of this type comprises the simultaneous change in runner blade pitch with change in degree of gate opening as dictated by the load demand.

This feature produces two highly desirable results which are not obtainable with fixed-blade type runners.

1) At low heads, it permits the attainment of relatively greater power as a result of the available greater blade pitch and increased discharge.
2) It permits the attainment of relatively high efficiency over a wide range of flow.

The second item provides for greater flexibility of operation, i.e., less change in the number of units in operation, than with any other type of unit, for wide flow variation. In the writer's experience with the Kaplan type this has been found to be definitely valuable.

With the experience gained in the design and construction of the Bonneville turbines, the McNary units, with the exception of the runner, represented mainly greater forces to be resisted, due to the higher head and power.

For the McNary runner, however, being of lower specific speed and for higher operating head than Bonneville, an increase in the number of blades from 5 to 6 was advisable. This change reduced the load on each blade and with greater aggregate blade area resulting, the cavitation characteristics were improved permitting the turbine setting to be higher with relation to tailwater elevation than the Bonneville runner would have required.

Notwithstanding the desirability of a field efficiency test, a glance at the Authors' Figure 5, "Section through Power House" shows the impracticability of obtaining accurate water measurement by any of the presently accepted methods, namely the Allen Salt Velocity Method, Gibson Method or Current Meters. Both the Allen and the Gibson Methods require appreciably greater length of intake passage than is provided, while the problems of angularity of flow and size of passages prohibit the accurate use of current meters.

Without a field test of the full size unit or prototype, the laboratory test of the model must be resorted to. Authors' Figure 6 represents the performance of a model that is homologous to the prototype, including intake passages, case and draft tube. The ratio of runner diameters is 280/12; the power is stepped up by the ratio of the net heads to 3/2 power, and by the

1. Chf. Engr., S. Morgan Smith Co.

runner diameters squared. The efficiency is stepped up by the Moody formula as indicated, the losses of the model being reduced by the ratio $(12/280)^{1/5}$.

Aside from the predicted performance as stepped up from the model, the index method of testing provides information as to the relative performance at various values of output.[2] This method has now become part of the ASME Test Code on Hydraulic Prime Movers. Briefly, the index test involves the determination of the difference in piezometric pressure at two selected points in the turbine case, and considering that the flow through the turbine varies with the square root of this pressure difference.

This Discussion's Figure 1 has been prepared to show the relative efficiency curve as compared with the model. This comparison is on the basis of gross head. Curve (1) shows the model performance with laboratory efficiency and the power stepped up as above described. The model efficiency is increased in Curve (2). The index test results with the maximum efficiency arbitrarily chosen at 93.8 per cent are set forth in Curve (3).

The tendency of the index test to show less variation in efficiency with load variation than the model curves is consistent with the Kaplan turbine experience of the writer's company. That is, there is a tendency for the prototype curve to move to the right as compared with the model.

The sharp break at the end of Curve (3) is due to cavitation. The power indicated by Curves (1) and (2) represents the model power under cavitation-free conditions. It is of decided interest to note that whereas the prototype shows maximum power of 138,000 Horsepower as determined by cavitation, the corresponding value on the model under the same sigma is 130,000 HP.

The Authors, under "Hydraulic Turbines" state "The guaranteed efficiency at the 80 foot rated head is specified to be not less than 86 per cent." To this sentence should be added "at 111,300 Horsepower output." 86 per cent efficiency at this output requires materially higher values at lower outputs.

The material increase in power above this rating as subsequently attained by the model (Authors' Figure 6) was to a great extent the justification for the increased rating of the Dalles Turbines to 123,800 Horsepower under a head of 81 feet.

Figure 2 is a sectional elevation of the McNary turbine. The main difference between these proportions and those for Bonneville is in the increased diameters of the shaft and blade servomotor.

BRIG. GEN. O. E. WALSH.[3]—The paper "Engineering Advancements at McNary Project" by Louis E. Rydell and Glenn H. VonGunten presents in a concise and extremely brief manner a most interesting but highly complex subject. Under the same subject heads that they have used, the writer will discuss certain features that he believes have merit and should be considered with the paper.

Navigation

The authorized 27-foot-depth ship channel from Vancouver to The Dalles might be considered to be completed from the wording used in the paper.

2. See "Index Testing of Hydraulic Turbines," by G. H. Voaden, ASME Transactions, July, 1951.
3. Vice-Pres., Portland General Electric Co., Portland, Me. Former Div. Engr., North Pacific Div. Corps of Engineers, U.S. Dept. of the Army.

S. MORGAN SMITH CO., YORK PENNSYLVANIA, U.S.A.

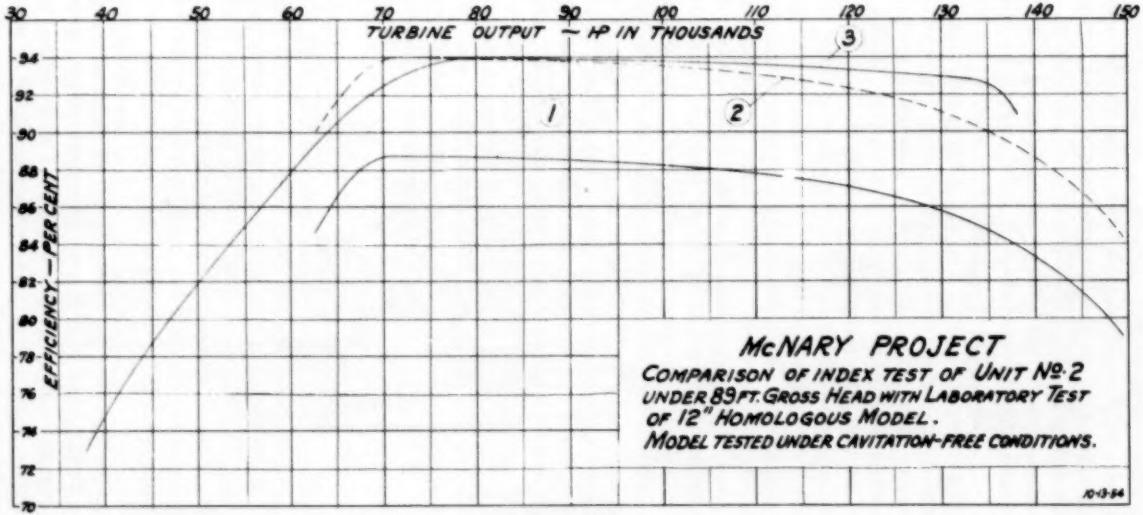
30 40 50 60 70 80 90 100 110 120 130 140 150
TURBINE OUTPUT — HP IN THOUSANDS
94 92 90 88 86 84 82 80 78 76 74 72 70
EFFICIENCY — PER CENT
1
2
3
McNARY PROJECT
COMPARISON OF INDEX TEST OF UNIT No. 2
UNDER 89 FT. GROSS HEAD WITH LABORATORY TEST
OF 12" HOMOLOGOUS MODEL.
MODEL TESTED UNDER CAVITATION-FREE CONDITIONS.
10-13-54

Fig. 1

NO. 50 REVISIONS	10-14-54	McNARY PROJECT COMPARISON CURVE FOR A.S.C.E. PAPER BY J. FISCH.
SCALE	APPRD. CHKD. DRAWN DATE	5250-DX-3

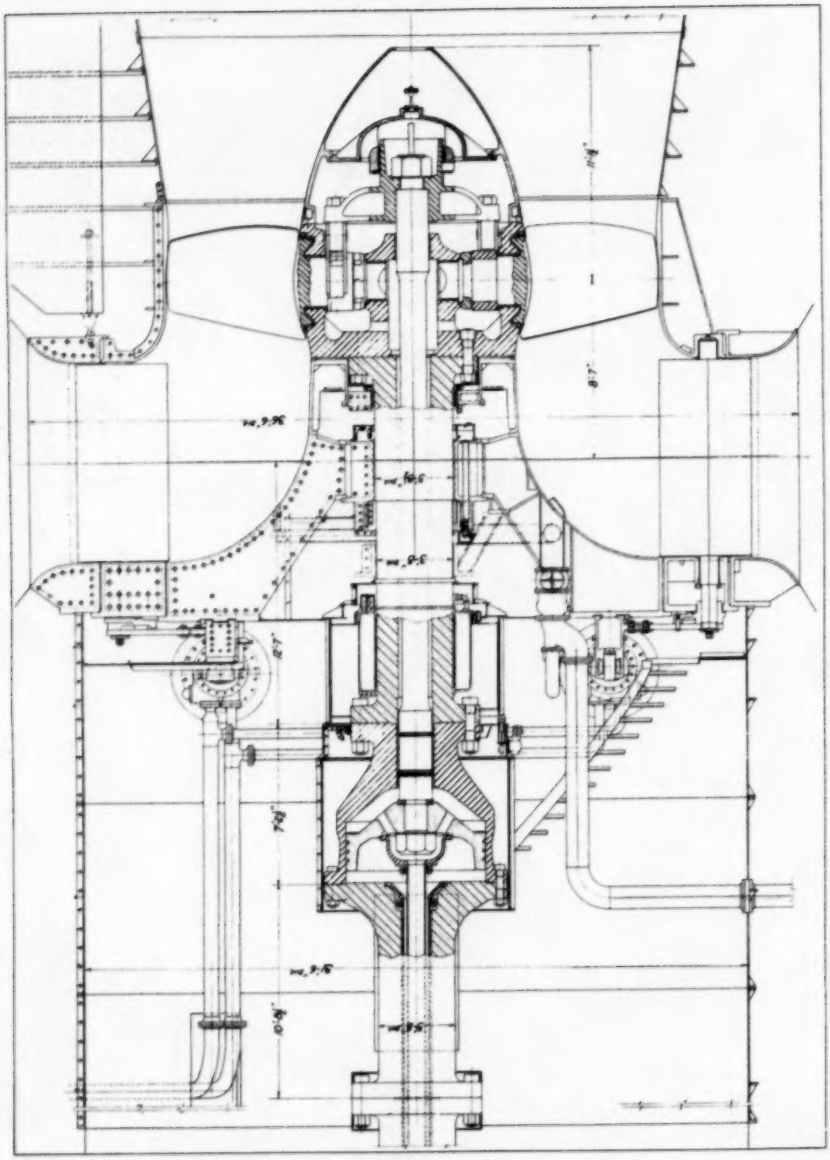

Fig. 2.

Adequate funds for its final completion have not been provided by the Congress at this time, as there has not been a concerted demand by navigation interests for them. Depths below Bonneville Dam have been maintained adequate for barge navigation, and this service is all that is now strongly demanded. Although a 27-foot-depth project is authorized, the controlling depth over the sills of the Bonneville lock will control the draft of vessels that can use the waterway when completed. This is 24.2 feet at low water.

Insufficient emphasis is given to the important part in providing tonnage that the many small ports and navigable tributary streams have played in developing the tonnage carried on the lower Columbia River. The ports at the mouth of the Columbia are likewise the bases for large fishing fleets and are the sites of a canning industry for these fleets, which add materially to the regional economy. Both of these factors add to the Columbia River's importance as a major navigable waterway.

The phenomenal growth in river traffic has occurred on a river with major railroads on each shore. The comprehensive development of the river for multiple-purpose uses has caused tremendous growth in the regional economy, and all means of transportation have profited thereby. This is the normal result to be expected by well planned economic river development.

The size lock provided at McNary was smaller than that demanded by local navigation interests. Its final dimensions were determined after a most comprehensive investigation and study including towing operations and lock sizes nation wide and including the economics of different sized structures with full consideration and knowledge that its size would govern the lock size at other projects on the Columbia, both downstream and possibly on the Snake River. That selected should provide for economical towing operations and should be entirely satisfactory for the Columbia River for many years into the future.

Mention is made of the model tests used during lock design, but the writer feels sufficient emphasis has not been made of their great contribution to final design. These tests guided the designers in location, lengths of guard and guide walls, all details of filling and emptying so as to control turbulence in the chamber and in the lock approaches. The timing of the valve operating controls, proper location and elevation of the control valves and many other difficult problems, not otherwise subject to satisfactory solution, were found in these extensive and exhaustive tests.

Power

After the principal low cost major projects of the Main Control Plan for the Columbia River are developed, the hydro-electric projects remaining in the great Columbia potential will be increasingly costly. It is therefore unfortunate that upstream projects providing badly needed storage to firm up the large secondary power now produced and as well provided urgently required flood control storage have not been carried on concurrently with downstream construction so as to produce the maximum possible power at the low cost sites.

No mention is made in the paper of the potential of pumped storage projects that might be developed in lieu of thermal plants for peaking and firming up some of the existing secondary energy. This subject should have careful consideration in future planning along with stream or atomic power plants.

During the early development and design phases of the project, the closest kind of coordination with the Bonneville Power Administration on the

establishment of electrical criteria was essential. To establish these was difficult because of the many changes in transmission characteristics that were then under study, and the power board studies required to make firm decisions. Credit must be given to all that decisions so satisfactory to today's operations could be secured by required deadlines.

Fish Passage Facilities

In view of the fact that strong opposition exists in the Northwest to practically every dam project, without regard to purpose, by the fishery and sports interests it is well to mention several important items on this subject. Mr. Milo Bell was secured as a consultant on design of fish passage facilities on the McNary Project. Before employment, all fishery and sports interests both U.S. and state, had indicated in writing that he was highly acceptable. He did an outstanding job and composed many strong differences of opinion. McNary has fish passage facilities of the latest development at the time of construction.

In the development of the fish facilities, model studies again played an important part. The introduction of a salmon fingerling into the fish ladder model one day by a laboratory technician when all fishery interests were present, where it easily swam up and downstream and rested without effort in various still water areas, did much to allay fears on upstream migration. It, however, centered attention on downstream migration problems. An outgrowth of this was the Corps of Engineers sponsorship and funding of a research program now actively in progress to assist in getting more data to help solve this problem. This extensive research program is being executed by the specially qualified fishery services of the states involved and by U.S. Fish and Wildlife Service. Excellent progress is being reported.

An expensive and to the writer's mind entirely unnecessary fishway channel across the entire front of the power house, parallel to the power house collecting channel, was insisted upon by fishery interests based entirely on fear that some fish might jump out in passing from one end of the dam across the power house collecting channel to the fish ladder on the south shore. Its cost was about one million dollars. The few fish that possibly might have left the collecting channel would not, in the writer's opinion, justify this large expenditure of funds.

Spillway

Model tests here again paid big dividends in design and construction costs. A very careful determination of the coefficient of contraction on the spillway piers resulted in eliminating two spillway monoliths with their costly gates. They also made certain that the split taintor gate was not practicable.

Reservoir

Although not mentioned, the land acquisition problem was a tremendous one with every conceivable type of real estate problem presenting itself. It was carried on expeditiously and with an unusually small amount of criticism, indicating fair appraisals, consideration for those displaced and mutual respect of landowner and government for each other's rights.

Construction

This subject has so many facets each of which justifies a full paper that the writer will not attempt discussion on it. What is said covers the essential major phases and their highlights.

Project Economics

"Power Benefits" should not be confused with power revenues needed to provide for "pay-out." Benefits are measured by a more or less arbitrary indicator based on a yardstick developed by the Federal Power Commission, the Bonneville Power Administration and the Corps of Engineers jointly, to measure benefits in an area almost exclusively served by hydro power. To compare McNary or other Columbia River hydro power projects with a steam plant, the usual procedure would give much greater economic justification and be unrealistic for the region for the present.

Revenue for "pay-out," however, is the cash that must be collected by the Bonneville Power Administration for deposit in the U.S. Treasury for the credit of the McNary Project. By law rates for the sale of power must be established adequate to completely pay for the project in fifty years. "Pay-out" must cover costs of all operation, maintenance and replacements of power facilities, amortization of the capital cost, including interest during construction, which is allocated to power, interest on unamortized amount of power project cost and any upstream storage power benefits assigned to McNary. Similar costs for transmission must also be paid. In the Northwest a so-called "postage stamp" rate for the region is set and from gross revenues each project is credited with funds to cover "pay-out." Up-to-date a surplus has been collected.

Soon Bonneville Power Administration rates will have to be adjusted upward as present day more costly projects are added to the system. Present rates were established to pay out Bonneville dam, Grand Coulee dam, and the present transmission system, which were built largely during the depression years of the 1930's and these rates have been more than adequate to do this.

On the whole the short paper discussed covers well a most intricate and very large subject, each aspect of which fully justifies a full paper alone. The authors have done well and the project will always stand as a tribute to the many fine skillful engineers whose hard work and ingenuity has made much engineering and construction history.

H. G. ROBY,[4] M. ASCE.—The authors of the paper have done an excellent job of describing the McNary Project which has recently begun operation, and which will soon add nearly 1,000,000 kilowatts to the hydro capacity in the Pacific Northwest.

The restriction as to space available for the presentation of the paper has practically limited the authors to a summary of the essential features of the project. At every large undertaking there is usually one feature of unusual interest and originality, and the authors have not failed to give an account of the one that distinguishes this project. In the writer's opinion, a description of the McNary development given before a group of engineers, however

4. Head, Hydro Power Branch, Civ. Works Office, Chf. of Engrs., U.S. Dept. of Army, Washington, D.C.

greatly condensed, would be incomplete which omitted an account of the closure of the second step cofferdam. This was undoubtedly one of the most outstanding engineering and construction achievements accomplished since the end of World War II. It is a great credit to the members of the Walla Walla District Office, Corps of Engineers, who conceived and carried it out.

The authors have furnished the text for this discussion in their early statement that the McNary Project may be considered a symbol of "achievement by progressive engineering." The writer would like to point out the tremendous increase in power and size of low-head run-of-river turbines that has progressively been developed during the professional life-time of one engineer.

In 1908, Mr. Daniel W. Mead, later President of this Society, and also Honorary Member, was engaged in the design of the Kilbourn Project on the Wisconsin River which would develop an operating head of 17 feet. In order to secure a speed of 107 rpm on a 2100 HP generator, it was necessary to couple six 57-inch horizontal units in tandem. The best efficiency was 81%.

In the period 1910-1914, Mr. Mead also designed the Prairie du Sac plant, which was laid out for eight units, each consisting of four 64-inch turbines in tandem on a horizontal shaft. The units operate at a speed of 107 rpm, and under a head of 32 feet turn-out about 4800 horsepower.

During this period, twin runner horizontal units were also installed at the High Falls plant on the Peshtigo River, 85 foot head, 1900 horsepower each; at a plant at Alpena, Michigan, 16-foot head, 650 horsepower each; and at Twin Falls, on the Menominee River, 42-foot head, 1700 horsepower each. In the early years of this century, two runner, four runner and six runner units were typical of low-head installations.

The first important step in increasing the speed and horsepower of low-head units occurred about 1920 with the development of the fixed blade propeller type of unit which had a specific speed about 50% greater than the Francis type of runner. The improvement that was secured is shown quite clearly by a change made at the Kilbourn plant, already mentioned, where, in 1926, after the head had been increased to 22 feet by erosion of the tail-race, a six-runner unit was replaced by a single vertical propeller type unit which operated at 125 rpm and generated about 3100 horsepower.

In 1924-28, the Byllesby Engineering and Management Corporation built a plant at Ohio Falls, Louisville, Kentucky, at which were installed eight propeller type units, rated at 13,500 horsepower each at 34-foot head. The maximum head was 37 feet, and the runner diameter was 15 feet. These were the largest units that the wheel manufacturers were prepared to build at that time and the operating head was the highest they were then ready to recommend for this type of unit.

It was about at this time that the Chippewa Falls plant on the Wisconsin River was designed and built. The six propeller type turbines were fitted with blades that could be manually adjusted to obtain changes in pitch. The turbines deliver 5000 H. P. each at 29.6-foot head. The blades are adjusted by means of a manually-operated ratchet device attached to the main shaft in the turbine pit and moving the blades in a major operation. The changes in blade angle are therefore made seasonally, being opened for full gate, reduced head, operation during the spring run-off, and returned to a smaller angle setting for the rest of the year.

Although changing blade angles was a rather laborious operation, the fact that the turbines were built to permit the change indicates that it was early recognized that a considerable advantage is secured when a change in blade

angle can be made to correspond to the change in the river conditions. The turbines adopted at Chippewa Falls indicate the trend of thought that ultimately led to the development of the automatic adjustable blade turbine, the Kaplan unit.

The first Kaplan unit in the United States was installed about 1930 when the Safe Harbor Water Power Corporation adopted it for the plant it was building on the Susquehanna River, about 12 miles below Columbia, Pennsylvania. It is almost impossible to exaggerate the importance of this advance in the practice of low-head power plant design. These Kaplan units with blades that adjusted automatically as the load changes, and which could be manually adjusted for changes in operating head, as compared to fixed blade units, showed such a large increase in output and dependable capacity that they justified the 20% increase in cost as compared to the fixed blade units.

The initial installation at Safe Harbor consisted of six 42,500 horsepower units operating at 109.1 rpm and 55 feet head. The runners are 18 feet 4 inches in diameter, and discharge about 9000 cfs at full gate and normal head.

The increase in speed of these Kaplan units, resulting in lower costs of generators, the smaller space requirements, and the gain in output and capacity, both at part gate and at reduced heads during flood conditions, as compared with Francis type units resulted immediately in a complete change in design of large low-head plants, with the uniform adoption of propeller type units and the abandonment of Francis type.

The successful introduction of the Kaplan units at Safe Harbor came just in time to make them available for use in the large program of run-of-river projects at T.V.A. From 1936 to 1944 seven projects of this type varying in rated heads from 36 feet to 65 feet, and in plant capacity from 97,200 kilowatts to 259,200 kilowatts were built and put into operation. The largest unit is rated at 36,000 kilowatts.

The next step in the "progressive engineering" of low-head units of large size was taken in the design and installation of the turbines planned to operate at heads varying from 30 feet to 69 feet at the Bonneville plant built by the Corps of Engineers on the Columbia River. The first two units, which went into operation in June and July 1938, were designed to generate 43,200 kilowatts at 50-foot head. By January '41, when the third unit was installed, the capacity of the unit, having the same runner diameter of 280 inches, had been increased to 54,000 kilowatts rated at 60-foot head. The remaining seven units of the same size were installed by December 1943.

When the McNary Project was under study, it was recognized that the Bonneville units were about as large physically as is practicable under existing shop conditions. The runner diameter for McNary was kept the same as for Bonneville, but the allowable total thrust was raised from 3,000,000 pounds to 4,000,000 pounds and the capacity was increased to 70,000 kilowatts at 80-foot head.

The next forward step is being taken at The Dalles plant now under construction between Bonneville and McNary where under approximately the same head as at McNary the units will be coupled to 78,000 kilowatt generators. At Ice Harbor, a project authorized for construction on the Snake River, the units under a slightly higher rated head, will probably be designed with a rated capacity of about 80,000 kilowatts.

At installations having a large number of units operating under a relatively small change in head, it is found economical to use propeller type units

with fixed blades. The number of units in operation can be varied to suit the load with each unit operated at or near the point of maximum efficiency. These conditions are present at the Barnhart Island plant which is a part of the St. Lawrence development now under construction. Turbines rated at 71,000 horsepower under a head of 82 feet have been selected, which have fixed blades bolted to the hub.

The writer refers in closing to his text, "achievements by progressive engineering." Progressive engineering has made it possible to advance from the use of six runners on a single shaft to secure a speed of 107 rpm on 1,500 kilowatt unit, up to the single runner units installed at McNary, which at 80-foot head and 85.7 rpm will actually develop about 80,000 kilowatts. It is probable that approximately the maximum size in physical dimensions has been reached. The problem of converting the energy in falling water at low dams to electrical energy on outgoing lines has been well worked out. The one direction that progressive engineering may now take appears to be the adaptation of Kaplan turbines to higher heads.